A STUDY ON MODES OF ROCK FAILURE UNDER UNIAXIAL COMPRESSION

A Thesis submitted in partial fulfillment of the requirements
for the award of the Degree of

Master of Technology
in
Geotechnical Engineering
Civil Engineering

by

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ROURKELA - 769008

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CERTIFICATE

This is to certify that the thesis entitled "**A STUDY ON MODES OF ROCK FAILURE UNDER UNIAXIAL COMPRESSION**" submitted by **Mr. ROHAN BISAI** (Roll No. 212CE1022) in partial fulfilment of the requirements for the award of Master of Technology Degree in Civil Engineering with specialization in Geo-Technical Engineering at National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

Date:

Place:

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Date: 24-05-2014

Place: Rourkela, India

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CONTENTS

ABSTRACT

Rock failure is a serious problem in rock engineering. Rock failure modes are complex and difficult. A comprehensive study on rock failure modes at laboratory scale is very important. It helps to recognize the adequacy of the support designed on the basis of the nature of an engineering work. With due need, this paper analyzes the failure modes of rock under uniaxial compression test. The nature of the principal failure mode is changed from axial splitting and shearing along a single plane to multiple fracturing in the case of rock specimens as uniaxial compressive strength (UCS) increases. Descriptions of different failure modes under UCS were presented below. It was found rock specimens generally fail through the rock materials in one or more extensional planes of the fracture development in brittle crystalline rock materials.

It appears that there are different types of failure and it is for the microscopic discontinuities in rock samples but not for the variations in sample preparation or test process or end boundary conditions. This study makes it possible to determine whether the rock samples failed in tension or failed in shear or in coupling of tension. It is hypothesized that the mode the sample fails affects the strength of rock samples.

LIST OF FIGURES:

CHAPTER 1

INTRODUCTION

1. INTRODUCTION

It is a medium with cracks, breaks, joints, bedclothes planes, and flaws. The quality of rock masses relies on upon the conduct of these or planes of shortcoming. The recurrence of joints and their introduction as for the designing structures have a critical unessential. Dependable characterization of the quality of rocks is extremely imperative for safe configuration of different sorts of civil structures, for example, curve dams, scaffold, docks, and tunnels.

Many numbers of studies are done to understand the failure mechanism and mode of failure under various stress condition considering the failure theories. Various different types of failure modes are there in rocks. Moreover the failure modes substantially vary with the effect of confining pressure. Rock under natural conditions experiences different stresses and fractures occur in a rock at a certain point when it crosses the threshold stress value. The rock fails with fracture giving rise to different failure modes under various stress conditions. They provide useful information for safe and economical design of various geotechnical structures involving rock. The prediction of failure through better design will significantly reduce the costs involved in construction and increase in the safety. The present study is attempted to review and understand the different failure modes of rock under the different stress conditions by conducting laboratory studies on rock samples.

1.1. OBJECTIVE

- To determine the strength behavior of rock masses.

- To determine the strength and elastic properties of intact samples and the prospective for degradation and disintegration of the rock material.

- After testing we can observe that the modes of failure make it possible to define whether the rock samples failed in tension, in shear or failed in coupling of tension and shear.

- To get useful information for safe and economic design of various geotechnical structures.

CHAPTER 2

LITERATURE REVIEW

2. REVIEW OF LITERATURE

2.1. INTRODUCTION

A geotechnical specification of the rock mass requires the information on the mechanical properties of intact rock. The mechanical properties of a rock mass are affected by discontinuities of rock mass such as planes of weakness, mineralogical variations, bedding planes, cracks, flaws, joints and etc.

On laboratory scale, there are numerous tiny discontinuities like micro-imperfections, between granular splits and micro-blemishes that oblige extraordinary discovery systems. These infinitesimal discontinuities influence the conduct of in place rock tests. This is tried in a Laboratory by **Szwedzicki and Shamu, (1996).** By this test we can realize that in rock mass there are numerous sort of infinitesimal discontinuities are there and for these properties can specifically influence the rock tests.

Reinhart, Paul and Gangal, Fairhurst and Cook, (1996) observed and classified Numerous modes of failure of cylindrical samples. But these observations were not considered when explaining the meaning of the results of uniaxial compressive strength tests. For these UCS tests we observed that there are different type of failures are there for different UCS values.

The location, orientation, size, density and microscopic discontinuities contribute to different modes of failure of the rock sample. This is suggested by **Szwedzicki and Shamu, (1999).** That means different modes of failure are shown for different type of microscopic discontinuities of rock samples.

2.2. Failure in Uniaxial Compression:

Rock examines under uniaxial compressive anxiety, on account of uneasiness centers around minor discontinuities, can fail in strain, in shear or in coupling of the weight and shear stresses. It relies on upon the presentation of the parts and the nervousness transport, the frustration is prompted being developed, shear or in coupling of shear and development. Dependent upon the presentation of the parts and the uneasiness scattering, the frustration is provoked in growth, shear or in coupling of shear and development. The complete sets of relations between the strain and tension portions are there and it may be made in a cross section structure. The lattice is known as the consistence cross section. The development demonstrating of the adaptable cross section was demonstrated attentively by Hudson and Harrison (1997).

Rock explores under uniaxial compressive strain, as an aftereffect of anxiety revolves around minor discontinuities, can come up short in strain, in shear or in coupling of the weight and shear stresses. It depends on upon the presentation of the parts and the strain development, the dissatisfaction is incited being created, shear or in coupling of shear and growth. Needy upon the presentation of the parts and the uneasiness disseminating, the disappointment is induced in development, shear or in coupling of shear and improvement. The complete sets of relations between the strain and apprehension areas are there and it may be framed in a cross segment structure. The grid is known as the consistence lattice. The advancement exhibiting of the versatile matrix was showed acutely by Hudson and Harrison (1997).

According to **Hudson (1989)**, if we wish to consider how the peripheral stress around a circular tunnel in rocks might cause failure, it is essential to understand the modes of failure in these circumstances.

Amann et al. (2011) indicated that whereas many failure criteria utilized in engineering analysis are primarily based on the process of shear failure. We can know that a failure criterion mainly depends on the shear failure.

Hudyma et al. (2004) indicated that uniaxial compression testing of rock sample can help the failure modes of rock masses. It states that we can know the types of mode of failure only by the uniaxial compression.

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Santarelli and Brown (1989) concluded that failure can manifest itself in different ways depending on the microstructure of the rock sample. That means microstructure affects the rock sample.

Szwedzicki (2007) and Basu et al. (2009) indicated that even when specimens are tested, a large range of uniaxial compressive strength (UCS) and various specimen failure modes are observed which could be attributed to micro structural differences particularly in the form of micro cracks. That means in various type of UCS value there are different type of failures are there and it depends on the micro cracks.

Maji (2011) expressed that the disappointment mode of a rock test under pressure influences the resultant quality of the example. As compressive quality of a rock material increments with the increment in binding weight, UCS gives a measure of least quality a rock specimen can have under packing and, thusly, the disappointment modes of rock materials under uniaxial squeezing can give valuable data to sheltered and financial outline of different designing structures. Albeit a few exploration lives up to expectations were done previously, our understanding of rock breakage is still indeterminate. This study means to comprehend the disappointment examples of stone (weak crystalline molten rock), sandstone (permeable sedimentary rock), and schist (anisotropic transformative rock) under uniaxial pressure and their connection with UCS. By this announcement we can realize that disappointment modes rely on upon the uniaxial packing and by these it is extremely helpful and monetary for any sort of structures on the rock.

The way the sample fails is reflected by the mode of the sample failure. This means that the mode of failure affects the resultant strength of the sample. Analysis of the mode of failure provides insights into the orientation of principal stress in rock samples. The study aims to understand the failure patterns or the mode of failure of rock sample under different uniaxial compression values.

2.3. MODE OF FAILURE:

Many of research has been conducted to explain the modes of cracks in rock samples. For hard and brittle cylindrical rock samples five distinct modes of failure were identified and it is stated by **(Szwedzicki and Shamu, 1999).** These five types of failure are given below. By this statement we can have a brief idea about the mode of failure of rock samples under uniaxial compression.

- **Simple extension**:

  It indicates a failure along a plane which is parallel to the way of compression. This failure doesn't happen over and again and this failure mode recommended that the specimen was reasonably free of discontinuities. In this mode of failure the rock specimen falls flat along a plane to the heading of compression.

- **Multiple extension** :

  The multiple extension mode represents a failure where two or more fractures run parallel to the long axis of this sample, with fractures vertical to that direction, multiple extension failure takes place. In this type of failure the rock sample fails in two or more cracks.

- **Multiple fracturing** :

Multiple fracturing incorporates specimen collapse along various planes at a few edges. This sort of failure of the example is frequently rapid and savage with an enormous amount of vitality being discharged. At the point when tensile failure is dominating, a large portion of the breakdown planes are in vertical and perpendicular bearings to the stacking power. At the point when shear powers are prevalent, the example breaks down along planes slanted and crossing the mid tallness of the specimen e.g. hour glassing or cone failure.

- **Multiple shear** :

When fracturing takes place along two or more planes situated obliquely to the direction of compression, but not being parallel to each other, the mode is called multiple shear. The shear surfaces can be identified by the dust left behind when fracturing occurs.

- **Simple shear** :

The single shear failure includes one or more real parallel shearing planes (zones) arranged at a diagonal angle to the path of most extreme pressure. The shear planes generally create over an unconfined a piece of the specimen. Single shear may incorporate shear failure coming about because of uneven stacking of the specimen. This happens when a solitary shear starts from the top or lowest part of the example and advances outwards. The greatest testing burden for straightforward shear is frequently low contrasted and different failures since the failure plane is regularly connected with a weak vein material. It creates the impression that shake examines in the uniaxial compressive test dominatingly fizzle in shear (basic or numerous).

Different types of mode of failures are shown below in fig 1. There are five types of failure are there.

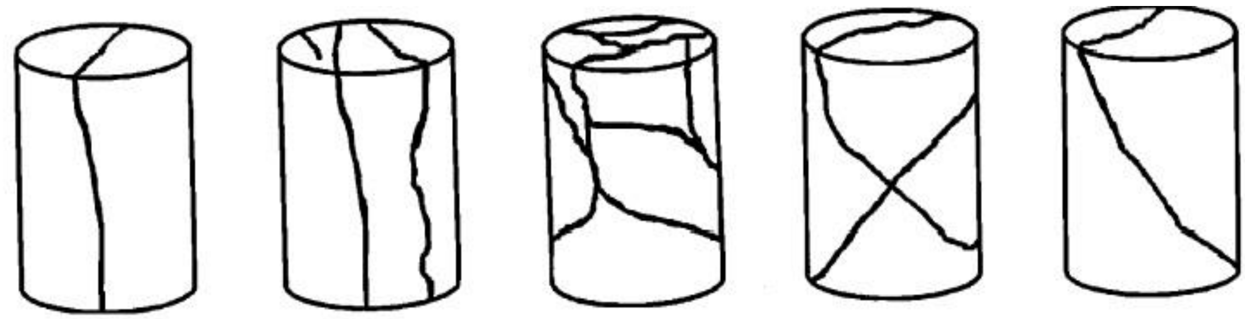


Fig. 1

Relation Between the Value of the UCS and the Mode of Failure:

It is watched that consequences of the UCS of man-made homogenous materials. It is conjectured that the aftereffects of tests on rock specimens are not strictly similar on the grounds that tractable and shear segments may differ in extent and it relies on upon the mode of disappointment. The explanation behind this is primarily because of discontinuities of rock material that influence the modes of disappointment and Shamu (1999) watched the impact of minute discontinuities on the uniaxial compressive quality of round and hollow rock tests. To know the impact of the mode of disappointment under uniaxial clamping on the quality of quality of specimens of distinctive lithology, a dimensionless parameter was presented. In diverse UCS esteem there are distinctive sorts of disappointments or distinctive mode of The maximum testing load for simple shear is often low compared with other failures since the failure plane is often associated with a

It is attested that the varieties in qualities of uniaxial compressive quality of specimens from the same lithology rely on upon the mode of disappointment. With the same mode different modes of disappointment happen on comparable specimens the varieties can frequently achieve great qualities. Presently we can state that the example from the same lithology however it have distinctive mode of disappointments for its different micro discontinuities of rock mass.

As a case, four UCS tests on chamber formed bordering examples of basalt that fizzled in distinctive modes are displayed. The example that fizzled in the basic shear mode had a computed UCS of 62 Mpa. The example which fizzled in the numerous shear mode had UCS of 90 Mpa. Two specimens fizzled in the various breaking mode. One specimen that fizzled transcendently in shear anxiety had a UCS of 215 Mpa and the other that fizzled basically in elastic anxiety had a UCS of 305 Mpa. We tried the tube shaped example of rock and get different qualities comparing to the distinctive mode of disappointment. It is expressed in the test results.

CHAPTER 3

LABORATORY TESTING

3. LABORATORY TESTING:

3.1. SAMPLE PREPARATION:

3.1.1. Collection and Storage:

Test material should be gathered from field as rough and large blocks, dressed squares or bored centers. The specimen is to be checked to demonstrate its unique position and introduction concerning guardian rock mass. Tests should be moisture sealed promptly after accumulation by waxing. We need to do it for moisture sealed example. They should be transported deliberately in a wooden box with saw dust. They might be put away in shade ensured from exorbitant changes in humidity and temperature.

3.1.2. Sample Drilling:

A heavy stiff machine with suitable clamping device for holding the sample shall be used for drilling. The drill travel shall be sufficient to permit continuous runs of at least 150 mm and preferably 250 to 300 mm without need for stopping the machine. The block shall be clamped tightly to a strong base to prevent any movement. Clean water shall be used for flushing and cooling the machine. For moisture sensitive rocks, compressed air shall be used. Laboratory coring shall be done with thin walled rotary diamond drill bits. The diameter of the core may vary from 35 to 150 mm.

Fig 2

3.1.3. Sawing and Cutting:

A 400-450 mm dia diamond saw with the procurement of portable trolley to encourage holding and development of the example might be utilized. The huge breadth diamond saw wheel should be utilized for substantial sawing. An exactness cut-off machine with 200 mm width diamond sharpened steel should be utilized. For accurate cutting, the exactness cut-off machine, if accessible may be utilized. For cross cutting, center should be clasped in a vee-block opened to allow entry of the wheel. The center should ideally be backed on both sides of the slice to abstain from spalling and lip shaping at the end.

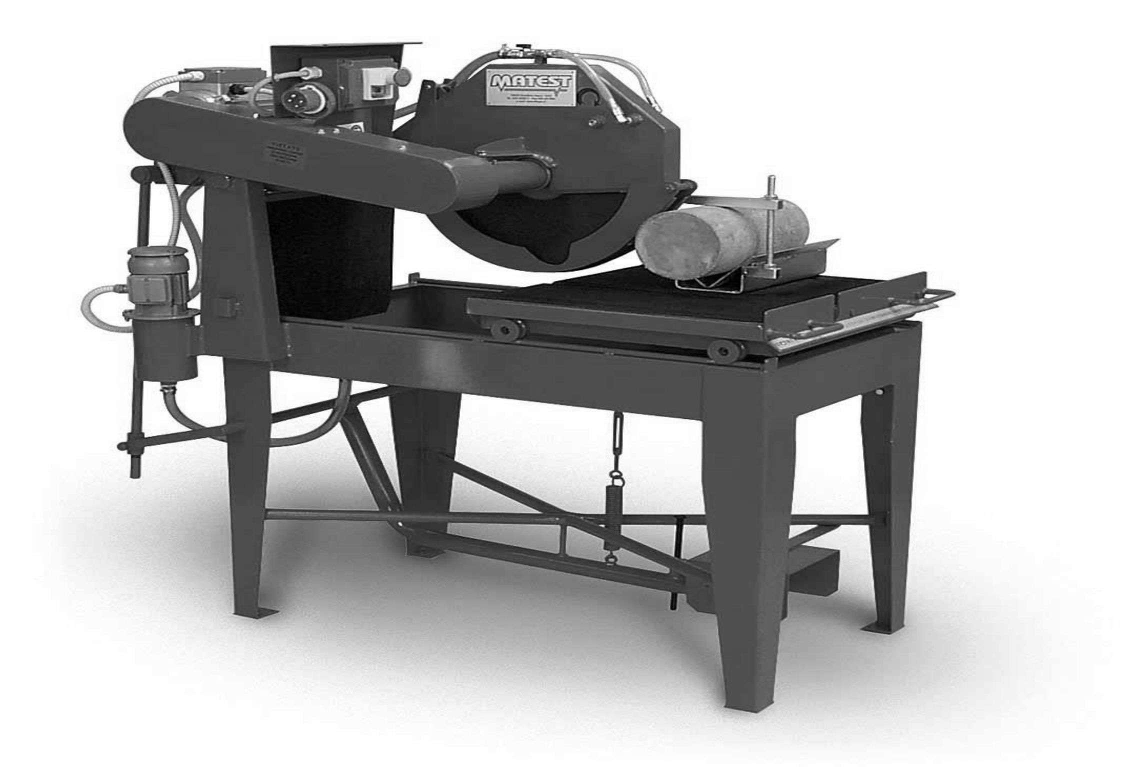


Fig: 3

3.1.4. Grinding:

The work should ideally be carried out dry without &e of any cutting or cooling fluids. For edge pounding, a device post processor or a stationary precious stone point may be utilized. The revolution should be decently moderate say in regards to 300 rev/min. Machine might likewise be utilized for fast end granulating of cylindrical samples. Test should be held specifically in the hurl and turned at 200-300 rev/min and the crushing wheel passed against it. Surface granulating should be utilized on wide surfaces of prismatic examples to attain closer tolerances.

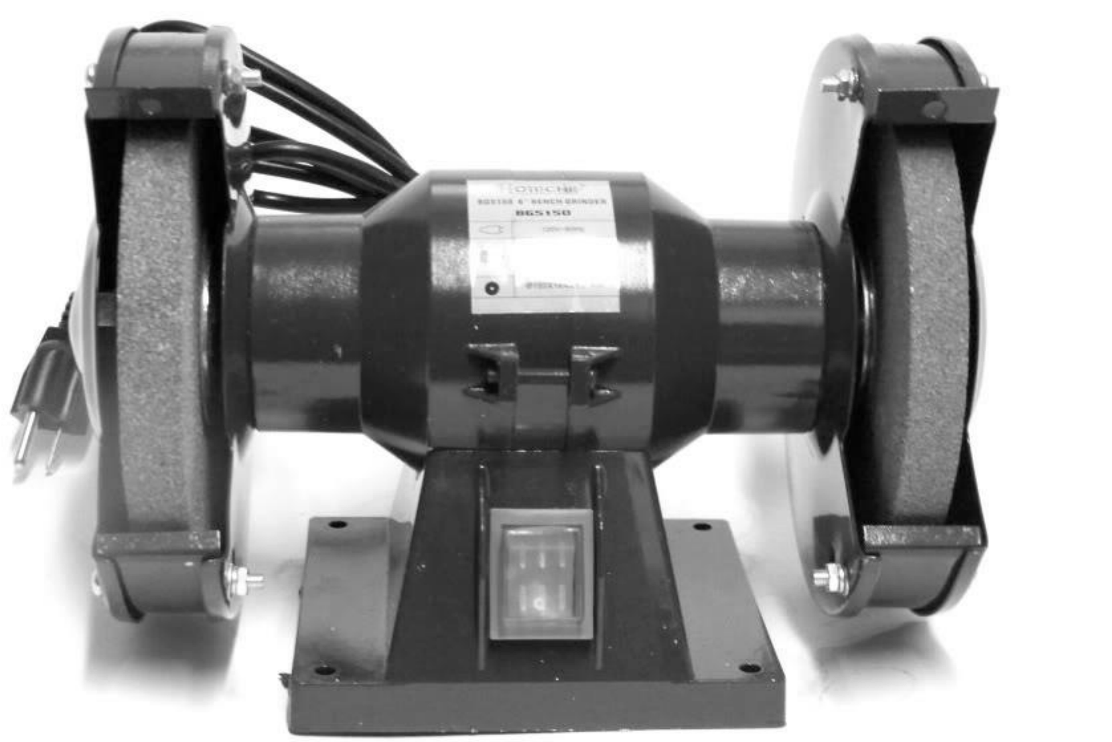


Fig: 4

3.1.5. Lapping:

The lapping machine may be a simple rotating iron disc with a minimum of attachments or an programmed one which can handle several samples. Suitable arrangements for clamping the specimens shall be provided. Lapping shall be done if considered necessary to put a final smooth finish on end surfaces of specimens. The cylindrical specimen shall be placed in a steel tube with close tolerance of about 0.05 mm. At the lower end of the steel tube is a steel collar which rests on the lapping wheel.

3.2. Shape and Size of Specimens:

The specimen diameter shall not be less than ten times the maximum grain size of the rock and preferably more than twenty times the maximum grain size. However, the recommended minimum size is 45 mm and in no case it should be less than 35 mm, in the latter case the tolerances shall be correspondingly reduced.

Specimen dimensions shall be checked during machining with a micrometer or vernier caliper. Final dimensions shall be measured nearest 0.1 mm. The final dimensions and tolerances shall be checked with a comparator.

Specimen ends should be flat to within 0.05 mm. They shall be parallel to each other within O.OO2D, where D is the specimen diameter. The ends shall be perpendicular to axis of the specimen within 0.001 rad (3.5 minutes) or 0.05 mm in 45 mm diameter specimen. The other surfaces of the specimens (cylindrical surface in the case of cylindrical specimen) shall be smooth and free from abrupt irregularities and straight to within 0.3 mm and the dimensions (diameter of cylindrical specimen) of the specimen shall not vary by more than O.2 mm over the length of the specimen.

3.3. Precautions for Specimens:

The examples should not be tainted with oils or different substances at any stage. On the off chance that tainting can't be maintained a strategic distance from, it should be absorbed a dissolvable like benzene or ch3)2co and afterward washed with clean water. Pollution of outer surfaces of completed examples might be stayed away from by utilizing gloves for taking care of and by putting examples against clean dry surfaces.

3.4. Determination of the water content:

Sample Specification:

A representative sample for testing should generally comprise several rock lumps. Each magnitude should be larger than the largest grain or pore size. Test sample should be free from presence of Micro-fissures of similar size if possible.

Calculation and Result:

The water content shall be calculated from the following formula:

Water content, $w = \frac{\text{Pore water mass } M_w}{\text{Grain mass } M_s}$ x 100 (percent)

$$= \frac{m_2 - m_3}{m_3 - m_1} \text{ x } 100 \text{ (percent)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \quad \text{eq. 3}$$

Where,

m_1 = Mass in g of the container with its lid at room temperature.

m_2 = Mass in g of the container with its lid and the sample at room temperature.

m_3 = Mass in g of the container with its lid and the sample after drying.

3.5. Determination of porosity and density:

Using Saturation and Caliper Techniques:

The method is applicable only to non-friable coherent rocks that can be machined and do not appreciably swell or disintegrate when they are oven dried or are immersed in water. The method is suitable when regularly shaped specimens are required for other test purposes.

Calculation:

i. For each specimen calculate the pore volume, V_V, by the following formula:

Pore volume $V_V = \frac{M_{sat} - M_s}{\rho_w}$

………………………………………………………….. eq. 4

ii. For each specimen calculate the bulk volume, V, from the external dimensions.

iii. For each specimen calculate the dry density, ρ_d, by the following formula:

Dry density $\rho_d = \frac{M_s}{V}(\text{kg/m}^3)$

………………………………………………………….. eq. 5

iv. For each specimen calculate the porosity, n, by the following formula:

Porosity $n = \frac{V_V}{V} \times 100$ (percent) ………………eq. 6

v. Calculate average values of porosity and dry density for the sample.

3.6. Determination of slake durability index:

Slaking Fluid: The fluid used in slake durability test is termed as slaking fluid.

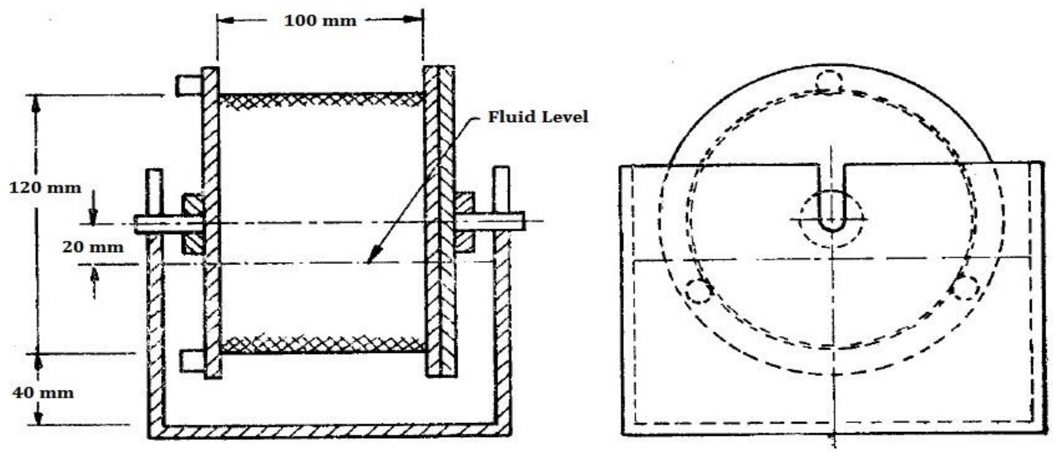


Fig:5 Line Diagram of Slake Durability test Apparatus

Calculation:

The slake-durability index (second cycle) is calculated as percentage ratio of final to initial dry sample weights as follows:

Slake durability index $I_{d2} = \frac{C-D}{A-D}$ X 100 (percent) ………….. eq. 8

Result:

A tentative sub-division of the slake-durability scale may be used for classification as given in Table 2.

Table: Tentative Sub-Division of Slake-Durability Scale

Slake Durability I_d	Classification
0 – 25	Very low durable
25 – 50	Low durable
50 – 75	Medium durable
75 – 90	High durable
90 – 95	Very high durable
95 – 100	Extremely high durable

3.7. Determination of tensile strength:

Terminology:

Core: It is any single solid cylindrical piece of rock obtained from drilling process.

Disc: It is any single circular solid piece cut out of the rock core.

Tensile Strength - It is the maximum tensile stress at failure. However, it is not unique characteristic of a brittle material and is dependent upon the type of test and the size of specimen.

Sample Specification: The diameter of the disc specimens for the Brazilian Test shall not be less than 45 mm and thickness shall be approximately equal to half the diameter. The total number of specimens should be such that at least 10. The specimens may be air dried in open air for 15 to 20 days after their preparation and then tested.

Figure: Line diagram of Brazilian test Apparatus

Calculation:

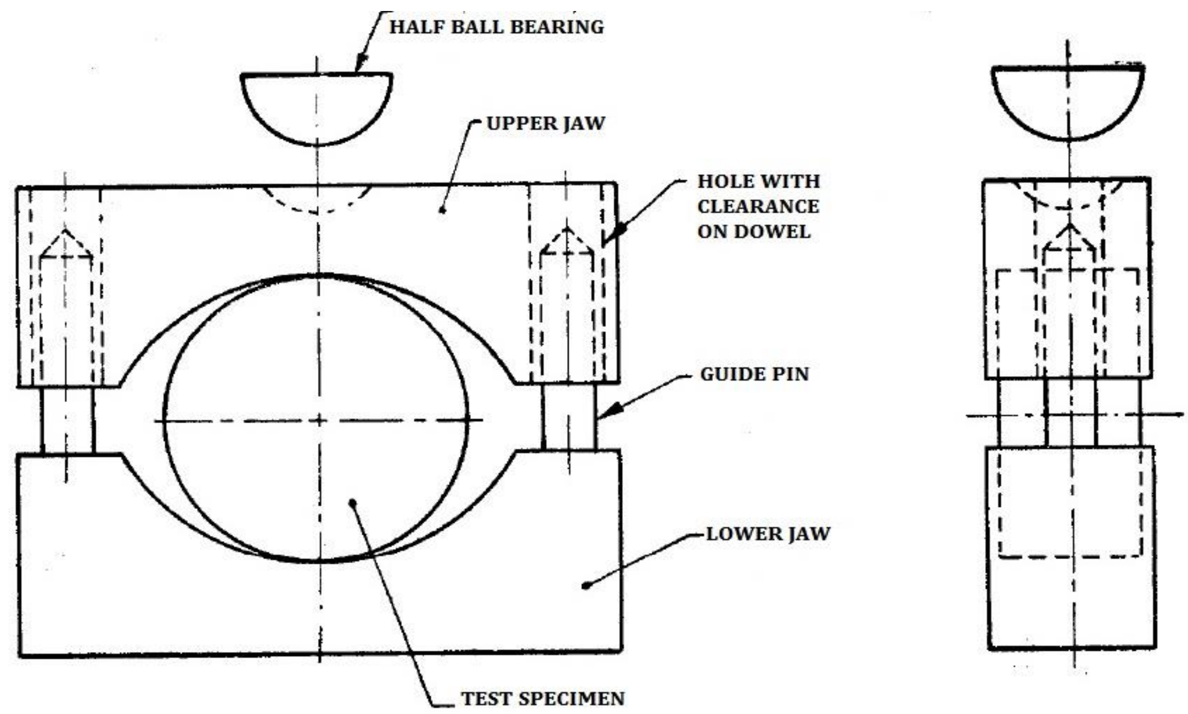
Tensile strength of rock shall be calculated from the following expression-

Tensile strength $q_t = \frac{2P}{\pi D t}$ ……………………………………………………………… eq. 9

where

q_t = Tensile strength in MN/m^2,

P = Load at failure in Newtons,



D = Diameter of test specimen in mm, and t = Thickness of test specimen measured at the centre in mm **fig: 6**

3.8. Determination of hardness:

Theory:

The Schmidt impact hammer is utilized for hardness determination of rock. The gadget which has both field and research facility utilization, comprises of a spring-stacked cylinder which is anticipated against a metal iron block which is in contact with the rock surface. The tallness of cylinder bounce back is taken as an observational measure of hardness. The strategy is of restricted use on delicate or hard shakes. The hardness of rock is subject to the sort and amount of different mineral constituents of the rock and the bond quality that exists between the mineral grams.

Calculation:

$$\text{Correction Factor} = \frac{\text{Specified standard value of the anvil}}{\text{Average of 10 readings on calibration anvil}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \text{eq. 10}$$

3.9. Determination of unconfined compressive strength:

Sample Specification:

The length to breadth degree of cylindrical shaped example might ideally be 2 to 3. The width of the example might be more than ten times the biggest mineral grain measure in rock, ideally 45 mm, yet in no case short of what 35 mm. The closures should be parallel to one another inside 0.002 D where D is the example width, The finishes might be perpendicular to the pivot of the example inside 0.001 radians (3.5 minutes) or 0.05 mm in a 45 mm breadth example.

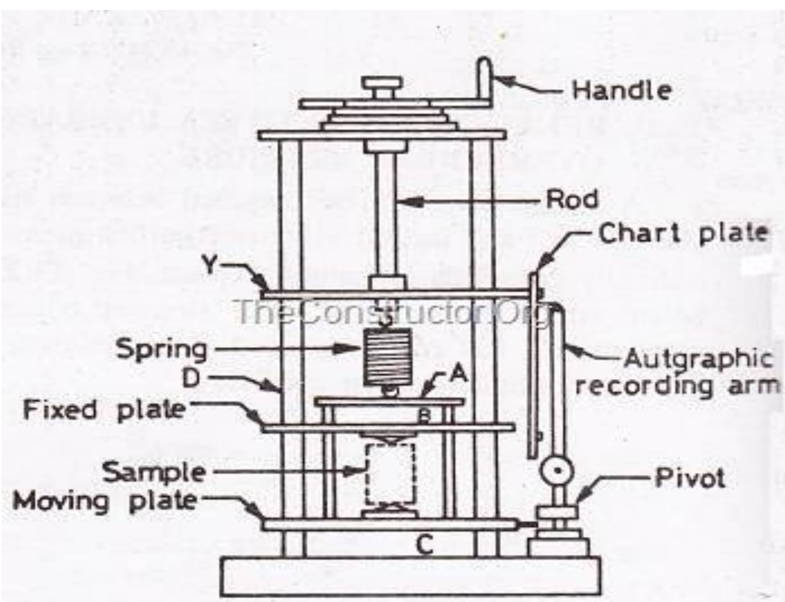
Calculation:

The unconfined compressive strength of the specimen shall be calculated by dividing the maximum load carried by the specimen during the test, by the average original cross-sectional area.

3.10 Determination of compressive strength:

Sample Specification:

Test example should be a right circular cylinder. The length to distance across proportion of the test example should ideally between 2 to 3. The width of the example might not be short of what ten times the biggest mineral grain in the rock and ideally at the very least NX size (roughly 54 mm). Ends of the example should be even to 0.02mm and might not withdraw from perpendicularity to the longitudinal hub of the example by more than 0.001 radians (about 3.5 minutes) or 0.05 mm in .50 mm. The tube shaped surface might be smooth and free from sharp irregularities and straight to inside 0.3 mm over the full length of the example.The measurements of the example might not change by more than 0.2 mm over the specimen length.



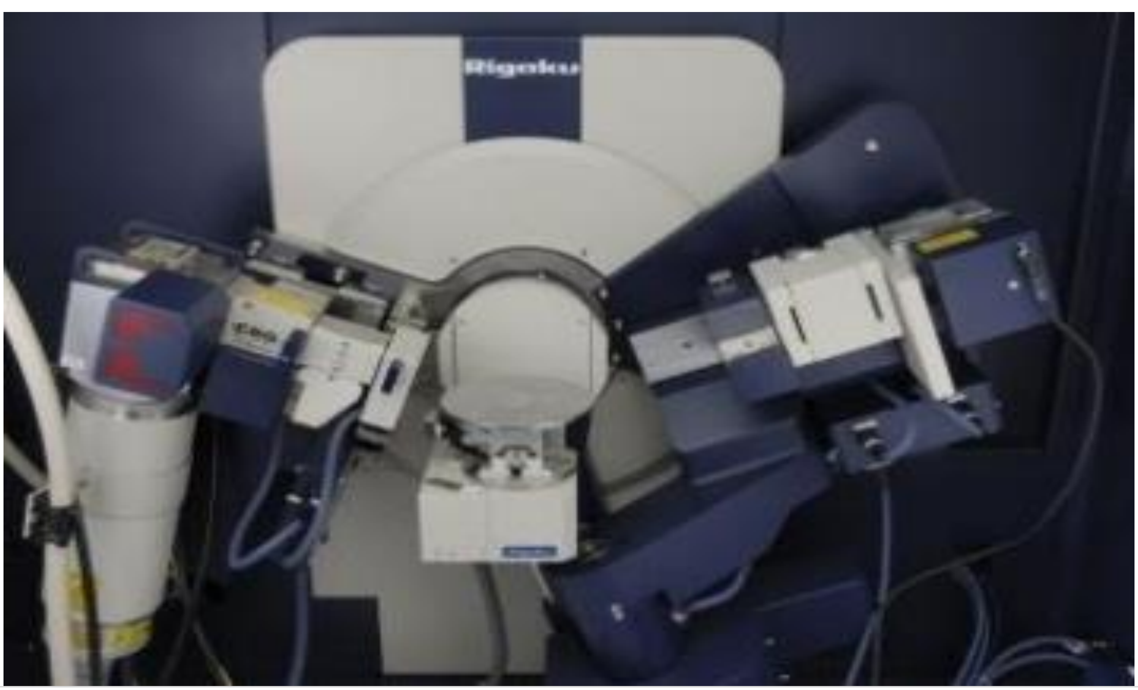
Calculation:

The compressive strength of the specimen shall be calculated by dividing the maximum axial load, applied to the specimen during the test, by the original cross sectional area of the specimen. The confining pressures and the corresponding strength values for different specimen are plotted with the confining pressures as abscissa and strength as ordinates.

3.11. X-RAY ANALYSIS:

This system is utilized within conjunction with SEM and is not a surface science procedure, and electron pillar strikes the surface of a directing specimen. The vitality of the shaft is commonly in the extent 10-20kev. This reasons X-beams to be emitted from the purpose of the material. The vitality of the X-beams emitted relies on upon the material under examination. The X-beams are created in a locale about 2 microns in profundity, and in this way EDX is not a surface science strategy. By moving the electron shaft over the material a picture of every component in the example could be gained in a way like SAM. Because of low X-beam force pictures generally take various hours to get. Components of low nuclear number are troublesome to locate by EDX.

Figure 8



3.12. SEM/EDX ANALYSES:

A SEM (Scanning Electron Microscope) could be used for high amplification imaging of just about all materials. With SEM in mixture with EDX (Energy Dispersive X-beam Spectroscopy), it is likewise conceivable to discover which components are available in diverse parts of an example.

CHAPTER 4
Sampling
Tests conducted
Slake durability test
Compressive strength test
XRD test

4.1. Sampling:

Sampling of the rock is very important for the testing. We know that for every type of tests we need different shaped or different sized sample. That's why we need more enough concentration to prepare the sample. In this case I followed some steps these are given below.

STEP- 1:

At first we have to search the site for collection of natural sample. I have collected this sample from JALDA, ROURKELA. After blasting I got the natural samples. They are in big sizes. I have collected this granite sample from this site. Then I took away these rocks to laboratory for sampling of rock. Then I stored this sample in suitable place.

STEP- 2:

After collection of sample and storage we have to prepare the sample in the right process. I drilled this sample by drilling machine. Drilling machine is a heavy stiff machine with suitable clamping device for holding the sample shall be used for drilling. Its core diameter is 38 mm for my drilling. I got 38 mm dia sample. After that we have to cut this granite samples in the right way.

STEP- 3:

After drilling of the sample we have to take the exact height of the sample. So I used the cutting machine to cut the rock sample. I got 38 mm diameter already and for UCS test we know that the length and diameter ratio is in between 2 to 3 that's why we need approximately 76 mm height of the sample. After cutting the samples I got 76mm heighted samples. But as the process of sampling we need to smooth the surface of the sample.

STEP- 3:

After cutting of samples sample height is 76mm and diameter of the sample is 38mm. but for the testing of rock we have to grind these samples. So that I used grinding machine. A grinding machine, often shortened to grinder, is a machine tool used for grinding, which is a type of machining using an abrasive wheel as the cutting tool. Each grain of abrasive on the wheel's surface cuts a small chip from the work piece via shear deformation. After the grinding we can use this sample for testing.

4.2. SLAKE DURABLILITY TEST

The slake durability test was carried out with 4 granite samples. Initial weights of the granite samples were taken as given below in the table.

SERIAL NO	INITIAL WEIGHT	WEIGHT AFTER 1st CYLCE	WEIGHT AFTER 2nd CYCLE	%RETAINED AFTER 1st CYCLE	%RETAINED AFTER 2nd CYCLE
1	316	300	280	95	93
2	314	299	278	95	92
3	316	302	280	96	94

It was observed that the granite sample percentage retention after the first cycle was found to be ranging between the values of 95% to 96 %.

While after the second cycle of the slake durability test it was found that the granite sample retention percentages ranged from 92% to 93.69%

Hence comparing the values of the first cycle and second cycle in the gamble's table the Granite sample was found to be very highly durable.

4.3. COPMRESSIVE STRENGTH TEST:

After completion of the sampling of rock we have the cylindrical rock sample. And we conduct the compressive strength test and we get various mode of failure on different samples and we get the maximum pressure for the failure.

CALCULATION:

Cross sectional area of specimen:

$A = \pi d^2/4$ where,

A= cross sectional area.
D= average specimen diameter.

Calculation of the volume of the specimen:

V = A (L) where,

V= volume of the specimen.
A= cross sectional area.
L= specimen length.

Calculation of specimen weight:

UW = M/V where,

UW= specimen unit weight.
M= specimen mass.
V= volume of specimen.

Calculation of the compressive strength in the test specimen from the maximum compressive load of the specimen:

σ= P/A where,

σ= compressive strength.
P= maximum load.
A= cross sectional area.

Sample 1:

P= 50 KN

A= 1134 mm^2 (diameter of the specimen)

σ= 44 N/ mm^2 (compressive strength)

Sample 2:

P= 80 KN

A= 1134 mm^2 (diameter of the specimen)

σ= 70.5 N/ mm^2 (compressive strength)

Sample 3:

P= 90 KN

A= 1134 mm^2 (diameter of the specimen)

σ= 80 N/ mm^2 (compressive strength)

Sample 4:

P= 100 KN

A= 1134 mm^2 (diameter of the specimen)

σ= 88 N/ mm^2 (compressive strength)

Sample 5:

P= 120 KN

A= 1134 mm^2 (diameter of the specimen)

σ= 106 N/ mm^2 (compressive strength)

Sample 6:

P= 160 KN

A= 1134 mm^2 (diameter of the specimen)

σ= 141 N/ mm^2 (compressive strength)

Sample 7:

P= 160.7 KN

A= 1134 mm^2 (diameter of the specimen)

σ= 142 N/ mm^2 (compressive strength)

Sample 8:

P= 180 KN

A= 1134 mm^2 (diameter of the specimen)

σ= 159 N/ mm^2 (compressive strength)

Sample 9:

P= 200.5 KN

A= 1134 mm^2 (diameter of the specimen)

σ= 177 N/ mm^2 (compressive strength)

Mode of failure:

There are different types of mode of failures are there in different compressive strength these are:

fig: 9 simple extension

Under 44 N/mm^2 it shows simple extension.

fig: 10 simple shear

Under 70.5 N/mm^2 it shows simple shear mode.

fig: 11 simple shear

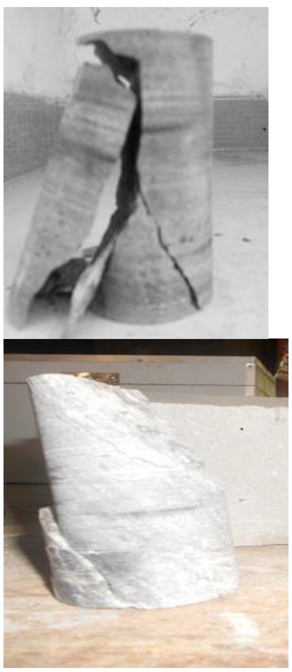
Under 80 N/mm^2 it shows simple shear mode.

fig: 12 multiple shear

Under 89 N/mm^2 it shows multiple shear mode.

fig: 13 multiple shear

Under 106 N/mm^2 it shows multiple shear mode.



Under 141 N/mm^2 it shows multiple fracture mode.

Under 159 N/mm^2 it shows multiple fracture mode.

Fig: 14 Multiple fracture

Under 177 N/mm^2 it shows multiple fracture mode.

Fig: 15 multiple fracture

After testing the samples we can observed that in different values of compressive strength there are different types of modes of failures such as simple shear, multiple shear, simple extension, multiple fracture etc. after the compressive test we identify that samples by its nomenclature and named it different type of mode of failures.

4.4. XRD TEST:

XRD test result is given below.by this figure we can know about the mineralogical components of granite.

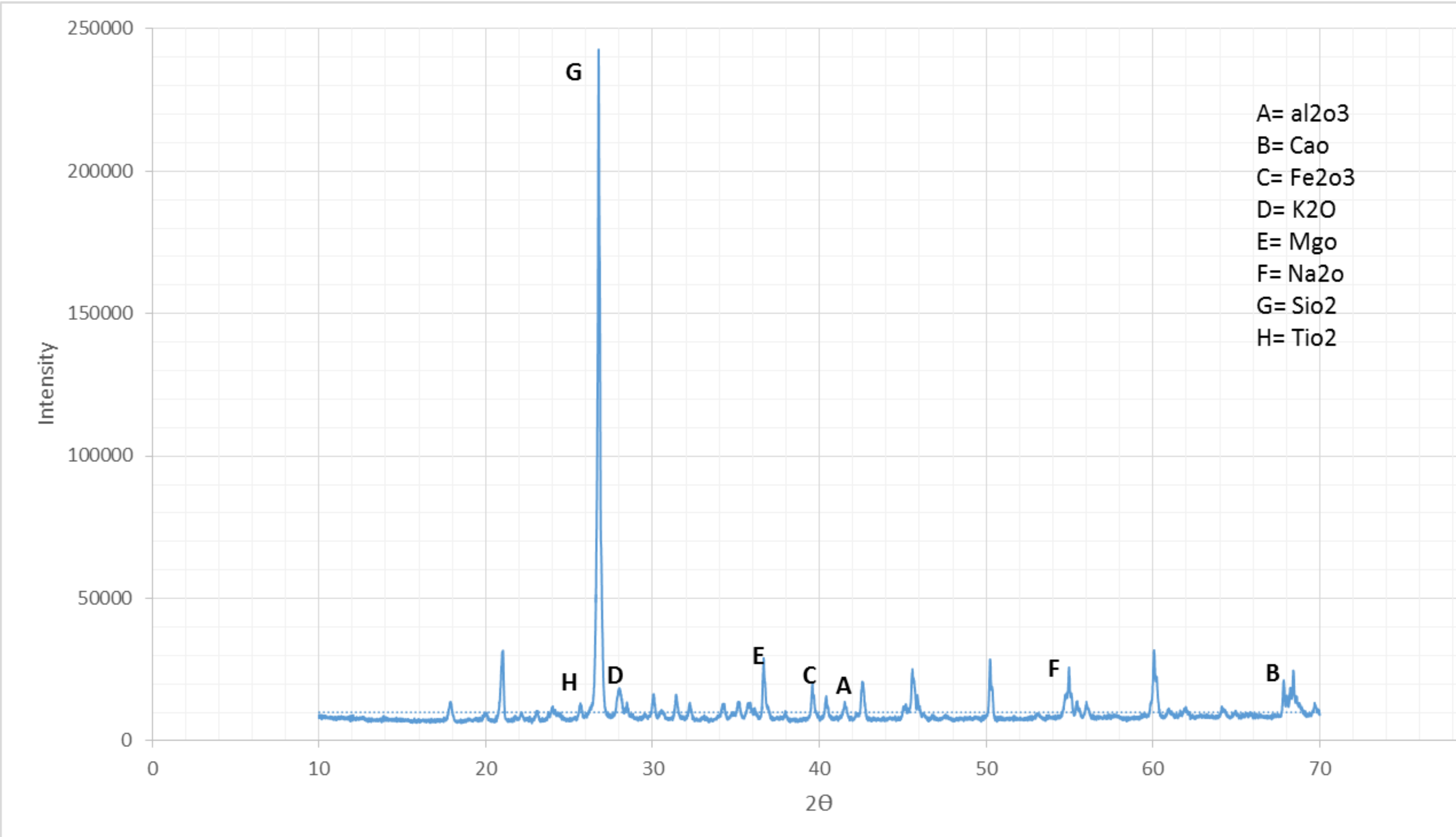


Fig 16

By this XRD test we can have a brief idea about the mineralogical composition of the granite sample. XRD test was conducted by the powder sample of the rock. By this test we can know the chemical composition of granite.

CHAPTER 5

DISCUSSION & CONCLUSION

5.1. MODE OF FAILURES:

Modes of failures are shown in a matrix figure:



SIMPLE EXTENSION **SIMPLE SHEAR** **SIMPLE SHEAR**


MULTIPLE SHEAR **MULTIPLE FRACTURE** **MULTIPLE FRACTURE**


MULTIPLE SHEAR **MULTIPLE FRACTURE** **fig:17**

5.2. Conclusions:

on the basis of present experimental study the following conclusions are drawn:

- The UCS of rock tested was obtained in extension are the highest, whilst the values obtained in shear are the lowest.
- The modes of failure are found to be dependent on UCS of the rock.
- UCS tests on cylindrical samples were conducted that failed in different modes are presented. The granite sample which is failed in the simple shear mode had a UCS of 80 MPa. The another sample which is failed in the multiple shear mode had a UCS of 140 MPa. Then two rock samples failed in the multiple fracturing mode. One sample that failed primarily in shear stress had a UCS of 160 MPa and the other that failed primarily in tensile stress had a UCS of 180 MPa.
- In slake durability three granite samples were tested and found to be highly durable.

It indicates that diverse kinds of failure are because of the microscopic discontinuities in rock tests rather than varieties in specimen arrangement, test method or end boundary conditions. It is watched that investigation of the modes of failure makes it possible to figure out if the rock examples failed in pressure, in shear or in coupling of strain and shear.

5.3. SCOPE OF FUTURE WORK:

1. The effect of temperature, confining pressure and rate of loading on the strength characteristics is may be studied.

2. Studies is to be made by introducing multiple joints in varying orientation.

3. Strength and deformation behavior of jointed specimens may be studied

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